VEHICLE SYSTEMS

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TOM BALES
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JACK SUDDRETH
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VEHICLE SYSTEMS PANEL

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
SUBPANEL REPORT

THOMAS BALES
SUBPANEL CHAIRMAN
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VEHICLE SYSTEMS - EXPENDABLE

INTRODUCTION
PERSPECTIVES OF THE SUBPANEL ON EXPENDABLE LAUNCH VEHICLE STRUCTURES AND CRYOTANKS

• NEW MATERIALS PROVIDE THE PRIMARY WEIGHT SAVINGS EFFECT ON VEHICLE MASS/SIZE
  - PROVIDE ROBUSTNESS IN DESIGN
  - YIELD SYSTEMS COST SAVINGS

• TODAY'S INVESTMENT
  - DISPROPORTIONATELY SMALL
  - SIGNIFICANT BENEFITS APPARENT
  - NO FOCUSED PROGRAMS IN MATERIALS AND STRUCTURES TECHNOLOGIES WITHIN NASA FOR LAUNCH VEHICLES

• TYPICALLY 10-20 YEARS TO MATURE AND FULLY CHARACTERIZE NEW MATERIALS
  - MANUFACTURING PROCESSES MUST BE DEVELOPED CONCURRENTLY
  - USER NEEDS CAN ACCELERATE MATERIALS DEVELOPMENT
    - SELECTED EXAMPLES (8090, 2219, 7XXX)
VEHICLE SYSTEMS

TECHNOLOGY NEEDS ADDRESSED BY THE EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS SUBPANEL

- MATERIALS DEVELOPMENT
  - ADVANCED METALLICS
  - COMPOSITES
  - TPS/INSULATION

- MANUFACTURING TECHNOLOGY
  - NEAR NET-SHAPE METALS TECHNOLOGY
  - COMPOSITES
  - WELDING

- NDE
### EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

**VEHICLE SYSTEMS PANEL**

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<tr>
<th>DESCRIPTION</th>
<th>MILESTONES &amp; RESOURCE REQUIREMENTS</th>
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<tbody>
<tr>
<td>• ADVANCED STRUCTURAL MATERIALS</td>
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**BACKGROUND & RELATED FACTORS:**

- In the last 10 years, many novel materials have been discovered that have applicability to space programs.
- These include but are not limited to:
  - Ultra lightweight Al alloys
  - Metal matrix composites
  - Polymer based composites
  - Development of these materials to maturity, and application in NASA programs, will have a profound influence on weight and cost savings as well as technological impact.

**RECOMMENDED ACTIONS:**

- Evaluate the application areas and state of maturity of these new materials.
- Design and analytical tool to realistically calculate cost and weight benefits arising from incorporation of such materials.
- Prioritize and select for funding the several materials that offer the most significant pay-off in the 3-10 year time frame.
- Insist on a teaming approach that includes NASA, producers and users and involves selection, design, manufacturing, and engineering criteria.

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<th>DESCRIPTION</th>
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<tr>
<td>• NEAR NET SHAPE FABRICATION TECHNOLOGY FOR VEHICLE STRUCTURES</td>
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**BACKGROUND & RELATED FACTORS:**

- Current vehicle system structures employ conventional materials and fabrication technology.
- Resultant structures are typically high cost and weight penalties are built into the design.
- Numerous near net shape fabrication opportunities exist, employing forming and joining technologies which are recognized, but require development.
- Payoffs will include significant improvements in performance and lower fabrication and total program costs.

**RECOMMENDED ACTIONS:**

- Initiate aggressive technology development program to demonstrate forming and joining processes suitable for all appropriate vehicle system structures.
- Identify vehicle structures design concepts and requirements amenable to near net shape processing.
- Select near net shape processes amenable to vehicle hardware.
- Develop candidate hardware program to demonstrate/validate fabrication technology.
## EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

### VEHICLE SYSTEMS PANEL

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<tr>
<td>• NDE OF ADVANCED STRUCTURES</td>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
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<tbody>
<tr>
<td>• NEED AUTOMATED REAL-TIME TECHNIQUES TO REDUCE COST</td>
<td>• NDE PROCESSES TO EVALUATE INCLUDE:</td>
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<tr>
<td>• HIGHER-STRENGTH MATERIALS NEED MORE RELIABLE NDE</td>
<td>o REAL-TIME X-RAY</td>
</tr>
<tr>
<td>• FRACTURE TOUGHNESS DRIVEN DESIGNS REQUIRE PRECISE FLAW IDENTIFICATION/DETECTION</td>
<td>o REAL-TIME ULTRASONICS</td>
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<td></td>
<td>o ACOUSTIC EMISSION</td>
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<td></td>
<td>o EDDY CURRENT</td>
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<td></td>
<td>• INCORPORATE AUTOMATION FEATURES</td>
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<td></td>
<td>• EVALUATE BUILT-IN SENSORS FOR COMPOSITES</td>
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<tr>
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<td>• AI-U TECHNOLOGY</td>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
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<tr>
<td>• SPACE PROGRAMS REQUIRE UNIQUE LIGHT WEIGHT MATERIALS</td>
<td>• FUND GOVERNMENT, INDUSTRY, AND PRODUCER PROGRAM TO ACCELERATE NEAR-TERM AND FAR-TERM AI-U DEVELOPMENT</td>
</tr>
<tr>
<td>• ALLOYS DEVELOPED FOR COMMERCIAL AND MILITARY AIRCRAFT NOT DIRECTLY APPLICABLE</td>
<td>• TAILOR MATERIALS DEVELOPMENT WITH SELECTED MANUFACTURING PROCESSES</td>
</tr>
<tr>
<td>• MATERIAL PRODUCERS ARE NOT CURRENTLY PLANNING TO INDEPENDENTLY DEVELOP THE REQUIRED LAUNCH VEHICLES ALLOYS, DEVELOPMENT WILL BE MARKET/USER DRIVEN</td>
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<tr>
<td>• NEAR-TERM AI-U ALLOYS CAN PROVIDE UP TO 15 PERCENT WEIGHT SAVINGS, LONGER-TERM ALLOYS HAVE POTENTIAL WEIGHT SAVINGS UP TO 30 PERCENT</td>
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<tr>
<td>• AI-U ALLOYS PROVIDE UNIQUE PROCESSING OPTIONS, I.E. SUPERPLASTIC FORMING</td>
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<tr>
<td>• LACK OF CO-OPER FUNDING LIMITS EFFECTIVENESS OF BRIDGING PROGRAM</td>
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BENEFITS OF USING AL-LI ALLOYS FOR CRYOGENIC TANKS

15% tank weight savings due to improved specific properties

2219 Integrially machined

Tank weight 50K lbs
Raw material 250K lbs

AI-LI @ $20/lb

80% raw material weight savings due to reduced scrap rate (80:20)

Integrially machined Tank weight 42.5K lbs
Raw material 213K lbs

Material costs
$ 1.0 M
$ 4.2 M
$ 3.2 M

$ 2000/lb to orbit

Cost-to-orbit benefit
$ 100 M
$ 85 M
$ 15 M

System costs savings
+$ 3.2 M
-$ 15.0 M
-$ 11.8 M

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS VEHICLE SYSTEMS PANEL

DESCRIPTION:
• COMPOSITE TECHNOLOGY FOR CRYOTANKS AND DRY BAY STRUCTURES (WITH EMPHASIS ON FIBER REINFORCED PLASTIC SYSTEMS)

BACKGROUND & RELATED FACTORS:
• PROCESSES MUST BE DEFINED TO ACCOUNT FOR FRP MANUFACTURING CAPABILITIES
• A TOTALLY INTEGRATED MATERIALS, DESIGN, MANUFACTURING, INSPECTION, AND TESTING PROCESS MUST BE IDENTIFIED WHICH WILL ACCOUNT FOR THE UNIQUE PROCESS NEEDS AND CAPABILITIES OF COMPOSITES
• WEIGHT REDUCTION POTENTIAL IS 20-30 PERCENT

MILESTONES & RESOURCE REQUIREMENTS:

RECOMMENDED ACTIONS:
• ESTABLISH COMPOSITE CRYOTANK SYSTEM DESIGN REQUIREMENTS AND LINER REQUIREMENTS
• DETERMINE STATE-OF-THE-ART CAPABILITIES IN FRP COMPOSITES FOR MATERIALS, DESIGN, MANUFACTURING, INSPECTION AND TESTING, SPECIFICALLY CONSIDER THE FOLLOWING:
  • IN-LINE INSPECTION
  • IN-SITU CURE METHODOLOGY
  • TOOLING APPROACH
  • JOINING TECHNOLOGY
  • COMPOSITE DAMAGE TOLERANCE AND REPAIR
• DESIGN A BASELINE CRYOTANK
• CONDUCT MANUFACTURING PROCESS TRADES
• ESTABLISH A BASELINE MANUFACTURING PROCESS
• DEFINE FACILITY SIZE REQUIRED TO SUPPORT FRP
MATERIALS AND STRUCTURES TECHNOLOGY FOR SPACE TRANSFER VEHICLES

Cryotank

- Materials
  - Al-Li
  - SiCp/Al MMC
  - Ti
  - RMC

- Low cost fabrication
  - Spun formed domes
  - SPF, Built-up structure
  - Filament wound RMC tanks
  - Explosively formed components

Core primary structure

- Materials
  - Al-Li
  - B/Al MMC
  - Gr/E

- NDE/durable materials
  - Real time radiography
  - Advanced ultrasonics
  - Space hardened materials
  - Protective coatings/platings

Benefits

- Advanced materials: 20-30% weight savings
  Increased payload
  Greater range
- Low cost fabrication: 30% cost savings
  Reduced assembly time
- NDE/durable materials: Increased reliability and vehicle life

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS VEHICLE SYSTEMS PANEL

DESCRIPTION:

- WELDING
  - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- WELDING USED AS JOINING TECHNIQUE ON ALL MAJOR AEROSPACE HARDWARE
- REPAIR OF WELDING DEFECTS MAJOR COST IN MANUFACTURING
- HUMAN ERRORS A MAJOR CAUSE OF WELDING DEFECTS
- LACK OF UNDERSTANDING OF PROCESS VARIABLES AND THEIR INFLUENCE ON PROPERTIES
- AUTOMATION POTENTIALLY CAN REDUCE NDE

RECOMMENDED ACTIONS:

- IDENTIFY PROCESS VARIABLES RELATIONSHIPS
- DEVELOP PROCESS MODELS
- IDENTIFY AND DEVELOP SENSORS FOR PROCESS MONITORING AND FEEDBACK
- IDENTIFY AND DEVELOP CONTROL HARDWARE AND SOFTWARE
- VERIFY AND VALIDATE PROCESSES AND CONTROLS
EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
VEHICLE SYSTEMS PANEL

DESCRIPTION:
- NEAR NET-SHAPE METALS TECHNOLOGY
  - BUILT-UP STRUCTURES FOR CRYOGENIC TANKS AND DRY-BAY APPLICATIONS

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
- INTEGRALLY STIFFENED STRUCTURES FABRICATED BY MACHINING FROM A THICK PLATE RESULTS IN HIGH SCRAP RATES (85%)
- LOW BUY-TO-FLY RATIO REQUIRED FOR ECONOMIC UTILIZATION OF NEW HIGH PERFORMANCE METALS
- BUILT-UP STRUCTURE APPROACH IS APPLICABLE TO BROAD RANGE OF STRUCTURAL COMPONENTS ENCOMPASSING TANKS AND DRY-BAY STRUCTURES
- PAYOFFS WILL INCLUDE SIGNIFICANT IMPROVEMENTS IN PERFORMANCE AND LOWER FABRICATION COST

RECOMMENDED ACTIONS:
- IDENTIFY VEHICLE STRUCTURES, DESIGN CONCEPTS AND REQUIREMENTS AMENABLE TO BUILT-UP STRUCTURE APPROACH
- DEVELOP FORMING AND JOINING PROCESSES TO FABRICATE APPROPRIATE STRUCTURAL PREFORMS
- DESIGN, FABRICATE AND TEST STRUCTURAL SUBELEMENTS
- DEMONSTRATE STRUCTURAL INTEGRITY UNDER REALISTIC SERVICE CONDITIONS
- VALIDATE TECHNOLOGY THROUGH DESIGN, FABRICATION AND TESTS OF FULL-SCALE TANKS AND DRY-BAY STRUCTURAL ARTICLES

SUMMARY OF THE DELIBERATIONS OF THE EXPENDABLE LAUNCH AND CRYOTANKS SUBPANEL

- THE MAJOR NEAR TERM ISSUE FOR AI-LI IS WHETHER FUNDING WILL BE PROVIDED TO ASSURE INCORPORATION IN THE NLS
  - PRODUCTION CAPABILITY IS IN PLACE FOR 8090, WELDALITE, AND 2090
  - NEAR NET SHAPE PROCESSES HAVE BEEN DEFINED AND SCALE UP ACTIVITIES ARE UNDERWAY
  - PROGRAM MANAGEMENT DECISIONS ARE REQUIRED TO EXPLOIT POTENTIAL
- MATERIALS TECHNOLOGY PROGRAMS WITHIN NASA ARE TOO LIMITED/RESTRICTIVE
  - NO FOCUSED PROGRAMS IN MATERIALS AND STRUCTURES TECHNOLOGIES WITHIN NASA FOR LAUNCH VEHICLES
  - CLEAR NEED FOR SUSTAINED/CONTINUING PROGRAMS TO SUPPORT USER NEEDS/LONG TERM NASA MISSIONS
- SIGNIFICANT NEEDS EXIST FOR STRUCTURAL ANALYSIS AND OPTIMIZATION PROGRAMS
- NDE TECHNIQUES AND METHODS MUST BE EXPLOITED TO ASSURE INTEGRITY, RELIABILITY AND COST REDUCTIONS
- JOINING AND BONDING TECHNIQUES AND CONCEPTS MUST BE DEVELOPED AND CHARACTERIZED FOR FUTURE LARGE LAUNCH VEHICLE APPLICATIONS

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REUSABLE VEHICLES SUBPANEL
ISSUE/TECHNOLOGY REQUIREMENTS

PERSPECTIVES
• FUTURE VEHICLES REQUIRE LOW COST, HIGH RELIABILITY, ROBUSTNESS, LOW MAINTENANCE, ON-TIME LAUNCH CAPABILITY
• CURRENT TECHNOLOGY GAPS EXIST RELATIVE TO ACCOMPLISHING THE ABOVE GOAL
• MAJOR TECHNOLOGY CATEGORIES
  - MATERIALS
  - STRUCTURAL CONCEPTS
  - FABRICATION/MANUFACTURING
  - DESIGN/ANALYSIS/CERTIFICATION
  - NON-DESTRUCTIVE EVALUATION (NDE)

MAJOR PAYOFF ITEMS

<table>
<thead>
<tr>
<th>MATERIALS</th>
<th>STRUCTURAL CONCEPTS</th>
<th>FABRICATION/MANUFACTURING</th>
<th>DESIGN/ANALYSIS/CERTIFICATION</th>
<th>NDE</th>
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<tr>
<td>COMPOSITES</td>
<td>NEAR NET SHAPES</td>
<td>BOND</td>
<td>CRITERIA</td>
<td>DESIGN FOR INSPECTABILITY</td>
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<tr>
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<td>INTEGRALLY-MACHINED</td>
<td>WELD</td>
<td>SYSTEMS</td>
<td>HEALTH</td>
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<td>TPS</td>
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<td>EXTRUDE</td>
<td>OPTIMIZATION</td>
<td>MONITORING</td>
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MAJOR PAYOFF ITEMS

DESCRIPTION:
- IN SPACE JOINING
  - WELDING
  - BONDING

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
- REPAIR TECHNIQUES FOR IN SPACE HARDWARE REQUIRED
- IN SPACE ASSEMBLY TECHNIQUES FOR LARGE STRUCTURES
- WELDING AND BONDING PROVIDE HIGH WEIGHT, LEAK PROOF STRUCTURES
- SOVIETS HAVE MADE EMERGENCY WELDING REPAIR ON MIR
- ELECTRON BEAM PROCESS ONLY PROCESS PRESENTLY USED IN VACUUM

RECOMMENDED ACTIONS:
- IDENTIFY AND DEVELOP WELDING AND BONDING PROCESSES FOR IN SPACE USE
- IDENTIFY LIMITING FEATURES OF ARC WELDING PROCESSES FOR USE IN SPACE
- DEVELOP WELDING HARDWARE/SOFTWARE FOR SPACE USE
- IDENTIFY SAFETY ISSUES ASSOCIATED WITH WELDING IN SPACE
- DEVELOP REMOTE CONTROL AND MANIPULATORS FOR OPERATIONS
- PLAN AND CONDUCT PROOF OF EXPERIMENT FOR SHUTTLE FLIGHT

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### REUSABLE VEHICLES SUBPANEL
#### ISSUE/TECHNOLOGY REQUIREMENTS

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<th>DESCRIPTION:</th>
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<tr>
<td>• Damage tolerant design for composite structures</td>
<td>• Publish damage tolerant design data book for composite structure</td>
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**MILESTONES & RESOURCE REQUIREMENTS:**
- Develop damage tolerant design data book for composite structure

**RECOMMENDED ACTIONS:**
- Develop damage tolerant design philosophy/criteria
- Assemble industry available test data
- Identify candidate fibers, resins, lay-ups, and manufacturing processes for damage tolerant skin designs
- Develop designed experiment utilizing damage tolerant testing to identify drivers (temperature range R.T. to 800°F)
- Utilize best skin designs for honeycomb panels and perform designed experiment to again identify drivers (temperature range R.T. - 800°F)

**BACKGROUND & RELATED FACTORS:**
- Space transportation missions are weight driven
- Composites reduce weight, reduce part count, and are adaptable to complicated shapes
- Unless properly designed, easily damaged
- Goal: Visually inspect only with minimal impact on weight

### DESCRIPTION:
- Optimized system engineering approach to ensure robustness

**DESCRIPTION:**
- Optimized system engineering approach to ensure robustness

**MILESTONES & RESOURCE REQUIREMENTS:**

**RECOMMENDED ACTIONS:**
- Develop concurrent engineering tools for flight mechanics, control, performance, leads, aerelasticity, manufacturing, operations, etc.
- Develop inter-disciplinary, total cost optimization and trades analysis tools
- Develop accurate statistical quantification tools for all sensitive parameters
- Develop atmospheric (winds) characteristics for design and operation
- Analytical tools to more accurately predict aerodynamics, plumes, acoustical, etc. induced environment data CFD
- Develop model synthesis tools to reduce model development
- Develop system probabilistic tools to guide optimization criteria

**BACKGROUND & RELATED FACTORS:**
- Low margins in the ascent operational envelope increases operational cost
- Maintenance and refurbishment of low-life parts is costly in inspection, analysis and change-out
- Robustness provides lower total cost, less rework, launch time, higher performance and less complex operation

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# Reusable Launch Vehicles and Cryotanks - Vehicle Systems Panel

**Description:**
- Maintenance and refurbishment philosophy

**Milestones & Resource Requirements:**

**Background & Related Factors:**
- Current reusable space vehicles are essentially de-certified as flight vehicles at the moment of touchdown.
- Recertification requires large scale disassembly, inspection, and test prior to next flight.
- These activities are labor intensive and account for a large part of the operations cost of the vehicle.

**Recommended Actions:**
- Examine maintenance and refurbishment philosophies of non-space vehicle operators to identify "lessons learned" for space systems.
- Define experience database from past reusable vehicle flights to allow statistical correlation of system failure modes, effects, and frequencies with maintenance and refurbishment approaches.
- Develop criteria to design for maintenance and assembly.
- Identify maintenance and refurbishment requirements for proposed vehicle technologies.
- Coordinate test philosophy and structural/design criteria efforts (i.e., design for assembly/repair approaches).

## Technologies

- Advanced structural materials
- AL-Li technology
- Near net shape fabrication technology for vehicle structures
- Near net shape metals technology
- Near net shape extrusions for structural hardware
- Near net shape: forgings
- Near net shape: spin forgings
- Welding
- In-space welding/joining
- Composites technology for cryotanks and drybay structures
- Joining technology for composite cryotanks
- Tooling approach for manufacturing large diameter cryotanks
- Develop a cure methodology for large composite cryotanks
- State-of-the-art buckling structure optimizer program
- State-of-the-art "shell of revolution" analysis program
- NDE for advanced structures
- In-line inspection of composites
- Scale-up of launch vehicles
- Launch vehicle TPS/insulation beyond 27.5 ft. diameter
- Design & fabrication of thin wall cryotanks for space exploration (5-20 ft. dia.)
7.1.2 Supporting Charts
## Description:

- Cryogenic Tankage
- Qualify AL-Li tankage

### Milestones and Resource Requirements:

- Sufficient data base for program managers to accept the material in new launch vehicle programs

## Background & Related Factors:

- Lightweight cryogenic tanks will increase the payload to orbit of various launch systems
- AL-Li has not reached the maturity to incorporate into the design without considerable additional effort beyond that currently funded.

## Recommended Actions:

- Conduct a program coordinated with existing programs to ensure that the necessary technology has been demonstrated and that engineering properties including AL-5056 statistically derived parent material and weld properties, fracture toughness, stress corrosion, resistance, etc., have been established.

## Description:

- Cryogenic Tankage
- Qualify composite tankage for use with liquid hydrogen

### Milestones and Resource Requirements:

- Establish the enabling technology to build, insulate and test a sub-scale tank. Tank test successful
- Identify where the technology is adequate and where development is required
- Demonstrate adequate technology
- Develop technology (subscale)
- Decide on manufacturing approach
- Design subscale tank with all the features of a full-scale tank
- Fabricate, insulate, inspect and test tank with LH2

## Background & Related Factors:

- Greater payload to orbit can be obtained with composite tanks suitable for use with liquid hydrogen
- Recent tests with a 1/3 full scale NASP tank with liquid nitrogen (LH2) demonstrated that the composite was not permeable at LH2 temperatures. Earlier small scale tests with gaseous helium at -420F demonstrated technically acceptable permeability and resistance to microcracking when thermally cycled. NASP 1/3 scale tank is currently in test. Thermal cycle tests and liquid hydrogen loading are being conducted.
# REUSABLE VEHICLES SUBPANEL

## VEHICLE SYSTEMS PANEL

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<thead>
<tr>
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</table>
| • CRYOGENIC TANKAGE  
  • QUALIFY COMPOSITE TANKAGE FOR USE  
  WITH LIQUID OXYGEN | • DEMONSTRATE THE ABILITY TO MEET SAFETY REQUIREMENTS  
  • FEASIBILITY PROGRAM $500K |

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<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
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| • GREATER PAYLOAD TO ORBIT CAN BE OBTAINED  
  WITH COMPOSITE TANKS SUITABLE FOR USE WITH LOX  
  • RECENT TESTS WITH A 1/3 FULL SCALE NASP TANK  
  WITH LIQUID NITROGEN (L<sub>N</sub>2) DEMONSTRATED THAT THE TANK WAS NOT PERMEABLE (IN AN ENGINEERING SENSE) AT L<sub>N</sub>2 TEMPERATURES. NASP 1/3 SUBSCALE TANK IS CURRENTLY IN TEST. THERMAL CYCLE TESTS AND LIQUID HYDROGEN LOADING ARE BEING CONDUCTED. | • ESTABLISH FEASIBILITY PROGRAM WITH THE FOLLOWING AS A MINIMUM:  
  • ESTABLISH SET OF DESIGN GROUND-RULES  
  • DEVELOP LINERS WITH DAMAGE THAT WILL PREVENT A CONFLAGRATION  
  • TESTS TO DEMONSTRATE NO CONFLAGRATION  
  • 1000 CYCLES OF RAPID O<sub>2</sub> PRESSURIZATION  
  • CONDUCT RAPID FILL WITH PARTICLE IMPINGEMENT  
  • BURST TEST |

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| • CLEAN AIR ACTS MANDATE ELIMINATIONS OF FREON BLOWING AGENTS  
  • ROBUST DESIGN PHILOSOPHY DICTATES DURABLE TPS SYSTEMS  
  • LONG DURATION SPACE MISSIONS REQUIRE SPACE QUALIFIED TPS MATERIALS TO SURVIVE ENVIRONMENT AND NOT CREATE DEBRIS FOR OTHER CRITICAL OPERATIONS | • CONTINUE ALS ADP TO DEVELOP ALTERNATE BLOWING AGENTS  
  • LOOK BEYOND NEAR-TERM FIXES TO FUND LONG-TERM REPLACEMENT MATERIALS  
  • DEVELOP ROBUST/REUSABLE OR EASILY REPLACEABLE TPS |
### REUSABLE VEHICLES SUBPANEL
#### VEHICLE SYSTEMS PANEL

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<td>• DURABLE PASSIVE THERMAL CONTROL DEVICES AND/OR COATINGS</td>
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<td>• REUSABLE CVT PROGRAM REQUIRES LIGHTWEIGHT DURABLE INSULATION FOR MINIMUM COST AND QUICK TURN AROUND</td>
<td>• DEVELOP ROBUST HIGH PERFORMANCE, LOW COST AND REUSABLE THERMAL CONTROL DEVICES AND/OR COATINGS</td>
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<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DEVELOPMENT AND CHARACTERIZATION OF PROCESSING METHODS TO REDUCE ANISOTROPY OF MATERIAL PROPERTIES IN A-LI</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• THE ANISOTROPY OF A-LI ESPECIALLY THE REDUCED STRENGTH IN THE SHORT TRANSVERSE DIRECTION SIGNIFICANTLY IMPACTS THE UTILITY OF A-LI APPLICATIONS</td>
<td>• REFINING EXISTING LABORATORY SCALE PROCESS TO PRODUCE ISOTROPIC A-LI</td>
</tr>
<tr>
<td>• DESIGN ALLOWABLES ARE FREQUENTLY DICTATED BY THE S-T STRENGTH (PREVENTING THE ACHIEVEMENT OF MAXIMUM BENEFIT FROM A-LI USE) AND COMMERCIAL AIRCRAFT BUILDERS HAVE HESITATED TO USE A-LI BECAUSE OF CONCERN OVER THE LONG TERM EFFECTS OF ANISOTROPY</td>
<td>• SUPPORT SCALE-UP OF LAB PROCESSES TO PROTOTYPE COMMERCIAL PRODUCTION VOLUMES</td>
</tr>
<tr>
<td></td>
<td>• CHARACTERIZE MATERIAL PROTOTYPES OF A-LI PRODUCED BY THESE METHODS</td>
</tr>
</tbody>
</table>

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## REUSABLE VEHICLES SUBPANEL
### VEHICLE SYSTEMS PANEL

### DESCRIPTION:
- Durable Thermal Protection System (TPS)

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- Future reusable vehicle programs require lightweight/durable TPS for minimum cost and quick turn-around
- Durability for wind/rain and servicing operations is required
- Mechanically attachable TPS can provide access for inspection and replacement
- TPS for integral load carrying cryogenic tankage does not exist

### RECOMMENDED ACTIONS:
- Continue development of durable bond-on ceramic tiles
- Continue development of durable mechanically attachable metallic and ceramic designs
- Develop high temperature adhesives for bond-on designs
- Develop specific TPS designs for integral load carrying cryogenic tankage including high strength & temperature foam insulation; may involve ground purge system
- Demonstrate suitability of designs by fabrication and testing to appropriate wind/rain, acoustic, aeropressure, thermal requirements

### DESCRIPTION:
- Unpressurized ALI structures (interstages, thrust structures)
- Qualify ALI for use with unpressurized vehicle and stability limited structures

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- Major portions of vehicle structures are stability limited. These include compression and bending loaded structures. ALI alloys offer increased in specific stiffness of 20-40% over current aluminum alloys, with the potential for corresponding weight savings in these structures

### RECOMMENDED ACTIONS:
- Fund development and testing of demonstration of stability limited structures (thrust structures, intertank connectors, wing boxes)
- Coordinate with low cost manufacturing and near net shape activities
<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• NEAR NET SHAPE SECTIONS</td>
<td></td>
</tr>
<tr>
<td>• EXTRUSIONS</td>
<td></td>
</tr>
<tr>
<td>• FORGINGS</td>
<td></td>
</tr>
<tr>
<td><strong>BACKGROUND &amp; RELATED FACTORS:</strong></td>
<td><strong>RECOMMENDED ACTIONS:</strong></td>
</tr>
<tr>
<td>• COST OF SCRAP METAL ON INTEGRALLY MACHINED Härenard is NOT COST EFFECTIVE FOR NEWER METAL ALLOYS</td>
<td>• IDENTIFY CANDIDATE HARDWARE FOR LARGE EXTRUSIONS, ROLL AND INCREMENTAL FORGING PROCESSES</td>
</tr>
<tr>
<td>• RECENT ADVANCES IN ROLL FORGING AND_INCREMENTAL FORGING OFFERS SIGNIFICANT MATERIAL COST AND PART COUNT REDUCTIONS FOR LAUNCH VEHICLES</td>
<td>• DEVELOP CANDIDATE HARDWARE TO DEMONSTRATE VALIDATE FABRICATION TECHNOLOGY</td>
</tr>
<tr>
<td>• PROCESS PARAMETERS NEED TO BE DEVELOPED FOR EACH NEW ALLOY</td>
<td>• GENERATE DESIGN ALLOWABLES</td>
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<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• PRESSURIZED STRUCTURES</td>
<td></td>
</tr>
<tr>
<td><strong>BACKGROUND &amp; RELATED FACTORS:</strong></td>
<td><strong>RECOMMENDED ACTIONS:</strong></td>
</tr>
<tr>
<td>• PRESSURIZED STRUCTURES COMMONLY USED AS CREW COMPARTMENTS ON SHUTTLE AND SPACE STATION ARE CURRENTLY FABRICATED FROM CONVENTIONAL MATERIALS.</td>
<td>• CONTINUE DEVELOPMENT OF DESIGN CRITERIA FOR THESE STRUCTURES</td>
</tr>
<tr>
<td>• NEW APPLICATIONS SUCH AS NARP, SSTO, AND MTV W11 HAVE GREATER DEMANDS TO REDUCE WEIGHT WHILE BEING SUJEC TED TO HARSHER ENVIRONMENTS</td>
<td>• CONDUCT DEVELOPMENT TESTS TO DETERMINE THE APPLICABILITY OF THESE MATERIALS TO MEET THE REQUIREMENTS</td>
</tr>
<tr>
<td>• ADVANCED MATERIALS SUCH AS AH-L AND/OR COMPOSITES HAVE PROPERTIES CONCU DICE TO THE ABOVE REQUIREMENTS, INTEGRAL SKIN AND STRINGER, SANDWICH PANELS, etc., ARE ALL DESIGNS WHERE THESE MATERIALS WOULD PROVE ADVANTAGEOUS</td>
<td>• DESIGN AND FABRICATE TEST ARTICLES TO VERIFY THE APPROACH</td>
</tr>
</tbody>
</table>
### REUSABLE VEHICLES SUBPANEL
#### VEHICLE SYSTEMS PANEL

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• WELDING AND JOINING - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES</td>
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</table>

<table>
<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS</th>
<th>RECOMMENDED ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• REPAiR OF WELDING DEFECTS MAJOR COST IN MANUFACTURING</td>
<td>• IDENTIFY PROCESS VARIABLES RELATIONSHIPS</td>
</tr>
<tr>
<td>• HUMAN ERRORS A MAJOR CAUSE OF WELDING DEFECTS</td>
<td>• DEVELOP PROCESS MODELS</td>
</tr>
<tr>
<td>• LACK OF UNDERSTANDING OF PROCESS VARIABLES AND THEIR INFLUENCE ON PROPERTIES</td>
<td>• IDENTIFY AND DEVELOP SENSORS FOR PROCESS MONITORING AND FEEDBACK</td>
</tr>
<tr>
<td>• WELDING USED AS JOINING TECHNIQUE ON ALL MAJOR AEROSPACE HARDWARE</td>
<td>• IDENTIFY AND DEVELOP CONTROL HARDWARE AND SOFTWARE</td>
</tr>
<tr>
<td>• AUTOMATION POTENTIALLY CAN REDUCE NOE</td>
<td>• VERIFY AND VALIDATE PROCESSES AND CONTROLS</td>
</tr>
<tr>
<td></td>
<td>• DEVELOPMENT OF TelerOBotic CAPABILITY FOR ON-ORBIT REPAIR/MAINTENANCE/INSPECTION</td>
</tr>
</tbody>
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### MICROMETEOROID AND DEBRIS HYPERVELOCITY SHIELDS

<table>
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<tr>
<th>DESCRIPTION</th>
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<tbody>
<tr>
<td>• MICROMETEOROID AND DEBRIS HYPERVELOCITY SHIELDS</td>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS</th>
<th>RECOMMENDED ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• THE THREAT TO SPACE VEHICLES FROM ORBITAL DEBRIS HAS BEEN RAPIDLY INCREASING</td>
<td>• DEVELOP AND QUALIFY LIGHTWEIGHT SHIELDS AND ATTACHMENT TECHNIQUES</td>
</tr>
<tr>
<td>• CURRENT ALUMINUM DOUBLE-BUMPER SHIELDING IS VERY HEAVY AND NEWER SYSTEMS SUCH AS NEXTEL HAVE NOT BEEN QUALIFIED</td>
<td>• CONDUCT A PROGRAM TO EVALUATE LIGHTWEIGHT SHIELDING DESIGNS TO MEET THE THREAT REQUIREMENTS</td>
</tr>
<tr>
<td></td>
<td>• ESTABLISH AND VERIFY ANALYTICAL MODELS. GOAL IS TO MINIMIZE SECONDARY EJECT AS WELL AS DEVELOP AND QUALIFY AN ULTRA-LIGHTWEIGHT SHIELDING DESIGN</td>
</tr>
</tbody>
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### REUSABLE VEHICLES SUBPANEL
#### VEHICLE SYSTEMS PANEL

**DESCRIPTION:**
- State-of-the-art shell buckling structure optimizer program to serve as a rapid design tool.

**BACKGROUND & RELATED FACTORS:**
- Current emphasis on development of large complicated finite element programs suited to detailed analysis, not design optimization.
- Available codes are out of date, not comprehensive and user unfriendly.
- Will improve the quality and speed of both preliminary design and detailed design.

**MILESTONES AND RESOURCE REQUIREMENTS:**

**RECOMMENDED ACTIONS:**
- Provide following features:
  - Macintosh or Windows user interface with graphic displays and pull-down menus.
  - Simple user format designed for use by both design and analysis disciplines.
  - Complete library of stiffened shell configurations.

---

**DESCRIPTION:**
- Test philosophy.
  - Restrict structural test to a load factor that allows alternate usages of expensive hardware.
  - No test factor.

**BACKGROUND & RELATED FACTORS:**
- Hardware has been tested to destruction or yield to the point where it is unusable for other applications.
- Structures of advanced materials present significant cost to programs.
- "No test factor" may be used as an alternate where weight may not be critical.

**MILESTONES AND RESOURCE REQUIREMENTS:**

**RECOMMENDED ACTIONS:**
- Develop a test code that restricts test to loads which maximize the structures' "reusability." Independent tests should be conducted that allow for data extrapolation from the lower leads to qualify hardware.
## REUSABLE VEHICLES SUBPANEL

### VEHICLE SYSTEMS PANEL

#### DESCRIPTION:
- **REDUCED LOAD CYCLE TIME**

#### BACKGROUND & RELATED FACTORS:
- Long turnaround time load cycles greatly increase cost and restricts implementation of needed changes.
- Load cycle costs are excessive.

#### MILESTONES AND RESOURCE REQUIREMENTS:

#### RECOMMENDED ACTIONS:
- Provide an interdisciplinary loads analysis tool that outputs loads and stress instead of sequential loads and stress analysis.
- Develop model synthesis techniques to reduce model development.
- Develop an optimized code to reduce computer cost.

---

#### DESCRIPTION:
- **STRUCTURAL ANALYSIS METHODS**

#### BACKGROUND & RELATED FACTORS:
- Current analysis methods involve analysis being conducted by isolated groups and distributing results to next group in a serial fashion.
- Iterations are long and laborious.
- Analytical methods, particularly in the area of stability knock-down factors, should be reviewed, updated as necessary and formalized.

#### MILESTONES AND RESOURCE REQUIREMENTS:

#### RECOMMENDED ACTIONS:
- Develop electronically interfaced, self-checking, aeroelastic, thermodynamic, dynamic & stress analysis tools that allow rapid iteration and apply the benefits of concurrent engineering.
- Review available documentation on stability analysis deriving concurrence on knock down factors to be used in above analysis.
- Test as required.
### REUSABLE VEHICLES SUBPANEL
#### VEHICLE SYSTEMS PANEL

<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
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</thead>
<tbody>
<tr>
<td>• OPTIMIZATION OF STRUCTURAL CRITERIA</td>
<td></td>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CURRENT STRUCTURAL CRITERIA DOES NOT ALLOW ASSESSMENT OF VEHICLE RISK AS RELATED TO LOAD VARIABILITY, SUBSYSTEM REDUNDANCY AND FACTOR OF SAFETY</td>
<td>• DEVELOP SIMPLE PROBABILISTIC APPROACH WITH NECESSARY DATA TO DERIVE AND JUSTIFY STRUCTURAL CRITERIA</td>
</tr>
<tr>
<td>• LACK OF SIMPLE PROBABILISTIC APPROACH TO RISK ASSESSMENT STIFLES EXAMINATION OF REQUIRED FACTOR OF SAFETY TO MEET PROGRAM OBJECTIVES</td>
<td>• DEVELOP ANALYSIS TOOLS TO IMPLEMENT STRUCTURAL RELIABILITY APPROACH AND SELECTION OF FACTORS OF SAFETY</td>
</tr>
<tr>
<td>• CURRENT APPROACH IS TO USE F.S. ≥ 1.25 FOR UNMANNED AND F.S. ≥ 1.4 FOR MANNED SYSTEMS</td>
<td></td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DEVELOP AN ENGINEERING APPROACH TO PROPERLY TRADE MATERIAL AND STRUCTURAL CONCEPTS SELECTION, FABRICATION, FACILITIES, AND COST (TOTAL COST)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• STRUCTURAL SIMPLICITY REDUCES ASSEMBLY COST AND OPERATIONAL COST</td>
<td>• DEVELOP CONCURRENT ENGINEERING TOOLS (ALL DISCIPLINES) THAT PROPERLY TRADE BETWEEN MATERIAL, STRUCTURAL CONCEPT, FABRICATION FACILITIES, PERFORMANCE, AND OPERATION</td>
</tr>
<tr>
<td>• PROCESSING CAN INCREASE COST, MR HARDWARE, AND LOWER MARGINS (SENSITIVITIES)</td>
<td>• DEVELOP OPTIMIZATION CRITERIA FOR TOTAL COST</td>
</tr>
<tr>
<td>• TOTAL COST IS THE DRIVER, NOT JUST WEIGHT</td>
<td></td>
</tr>
<tr>
<td>• SEQUENTIAL ENGINEERING IS COSTLY</td>
<td></td>
</tr>
<tr>
<td>• SEQUENTIAL ENGINEERING TENDS TO HIDE SENSITIVITIES AND PROPER TRADES</td>
<td></td>
</tr>
</tbody>
</table>
7.2 PROPULSION SYSTEMS PANEL
7.2.1 Final Presentation